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ORIGINAL ARTICLE / *Thoracic imaging*

CT pulmonary angiogram with 60% dose reduction: Influence of iterative reconstructions on image quality

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KEYWORDS
Pulmonary CT;
Dose reduction;
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Abstract
Goals: To compare the quality of low-dose CT images with sinogram affirmed iterative reconstruction (SAFIRE), and full-dose CT with filtered back projection reconstructions (FBP).
Materials and methods: Fifty pulmonary CT performed by a dual-source technique (120 kVp; 110 mAs) with (a) the same energy in both tubes, and (b) the distribution of reference mAs with 40% in tube A (44 mAs) and 60% in tube B (66 mAs). Each acquisition allowed reconstruction of: (a) full-dose images (with both tubes) with FBP reconstructions (group 1); and (b) low-dose images (from tube A) reconstructed with SAFIRE (group 2).
Results: Group 2 images presented: (a) a significant objective reduction in noise measured in the trachea on mediastinal (16.04 ± 5.66 vs 17.66 ± 5.84) ($P = 0.0284$) and pulmonary (29.77 ± 6.79 vs 37.96 ± 9.03) ($P < 0.0001$) images; (b) a similar subjective perception of noise and overall image quality ($P = 1$), which was considered to be excellent in 66% (33/50) of the cases, with no influence on the detection of elementary pulmonary lesions of infiltration (98.4%; 95% CI = [96.9%—99.9%]).
Conclusion: Despite a 60% reduction in radiation dose, the image quality with iterative reconstruction is objectively better and subjectively similar to full-dose FBP images.

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Several recent studies have evaluated iterative reconstruction algorithms developed by the main manufacturers to reduce the radiation dose in numerous thoracic and non-thoracic CT applications [1—4]. To evaluate these algorithms in comparison to standard filtered back projection (FBP) reconstruction, several options have been used in the literature: evaluation with phantoms [5—7], comparison of paired populations [8,9], or evaluation of the same population in long-term CT studies [10—14]. Nevertheless, these comparisons are limited due to the difficulty of extrapolating experimental studies to patients or evaluating patients who do not have the same morphological characteristics and/or lesions for the two CT evaluations. Ideally, to compare image quality and visibility of normal and/or abnormal structures on CT with or without dose reduction, full-dose and low-dose sequences should be obtained simultaneously from the same acquisition for the same patient. For this, if simple-source CT technology is used, two successive sequences must be obtained for a patient during the same CT session, which is difficult in routine clinical practice because of the excess radiation that this entails. With the development of dual-source technology, this goal can be reached without additional sequences, because information can be selectively obtained from one or both tubes [15]. Based on this innovative methodological approach, we compared the quality of ''full-dose'' images with FBP reconstruction to reconstruction of images with ''60% dose reduction'', using second-generation sinogram affirmed iterative reconstruction (SAFIRE) in patients who were referred for a CT pulmonary angiogram.

Materials and methods

Population

All adult patients, who were referred for a single-energy CT pulmonary angiogram for the 5 months from April 2011 to August 2011, were eligible for evaluation with a dual-source single-energy CT protocol allowing comparative analysis of full-dose and low-dose images. The study population included 50 consecutive adult patients (28 men and 22 women), who presented for investigation of dyspnea with no history of lung disease ($n = 16$) or complicating one of the following existing diseases ($n = 34$): chronic obstructive pulmonary disease (COPD) ($n = 12$), idiopathic interstitial pneumonia ($n = 4$), lung cancer ($n = 7$), infectious lung disease ($n = 4$) or cystic fibrosis ($n = 6$). The study protocol was approved by the ethics committee of our institution, with no obligation to obtain informed consent from the patients before the CT scan or for analysis of CT data.

CT protocol

Acquisition protocol

CT pulmonary angiograms were obtained with a dual-source system allowing 128 slices per rotation (Somatom Definition Flash, Siemens Healthcare, Germany), using a research dual-source protocol provided by the manufacturer (Fig. 1). In this protocol, the X-ray tubes of the system functioned simultaneously at the same power (same kilovoltage, 120 kVp) without cardiac synchronization, with the following parameters: collimation = 64 × 2 × 0.6 mm, with az-flying focal spot; rotation time: 0.28 s; pitch = 1.2. Total milliamperage (total of reference mAs) was distributed between the two X-ray tubes to apply 40% of the reference mAs to tube A (44 mAs) and 60% to tube B (66 mAs). Modulation of milliamperage was automatic during acquisitions (Care Dose 4D, Siemens Healthcare, Germany). The protocol included an injection of 90 mL of iodated contrast agent at a concentration of 300 mg of iodine per milliliter (Xenetix 300, Guerbet, France) at a flow rate of 4 mL/s. Data acquisition was begun following a bolus injection with a region-of-interest placed on the ascending aorta and a threshold of 120 HU.

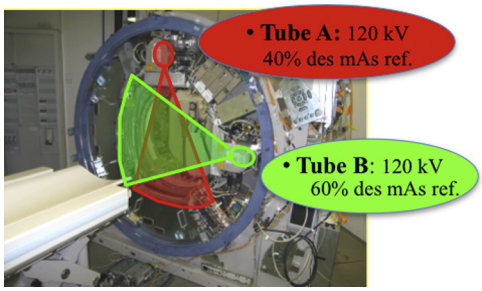

Figure 1. Illustration of the dual source research protocol providing ''full-dose'' images from data from both tubes (group 1) and ''low-dose''. Images with a 60% dose reduction from data from tube A (group 2) in the same sequence.

Reconstructions

Images were reconstructed in two different ways:

- ''full-dose'' images (group 1) were reconstructed from the raw data from both X-ray tubes combined, applying all reference mAs (110 mAs): 1 mm thick contiguous slices, reconstructed by FBP with the usual filters (pulmonary images: B50; mediastinal images: B20);
- ''low-dose'' images were reconstructed from the raw data from tube A using 40% of the total reference mAs (and thus 40% of the dose); these images resulted in a dose reduction of 60% (group 2). They were reconstructed with a second-generation sinogram affirmed iterative reconstruction algorithm (SAFIRE), using filters designed to closely correspond to the spatial resolution of FBP filters (or 50% and 10% of the modulation transfer function values of high contrast objects).

These were I50 filters for pulmonary and I20 for mediastinal 1 mm thick contiguous slices. Images from groups 1 and 2 were studied with mediastinal (width: 400 HU, center: 40 HU) and parenchymal (width: 1600 HU; center: —600 HU) windows.

Parameters evaluated

Image noise

Objective evaluation of image noise in groups 1 and 2 was performed by measuring the standard deviation of attenuation values in homogenous regions of interest on mediastinal images (B20; I20) in two anatomical regions (the tracheal lumen above the aortic arch; the descending aorta at the

level of the ventricular cavities) and pulmonary images (B50 and I50) in one anatomical region (the tracheal lumen above the aortic arch) based on the methodology reported by Pontana et al. [16].

The visual perception of noise, defined by the grainy aspect of the images, was evaluated on mediastinal and pulmonary images in groups 1 and 2. In each series of images the noise was considered to be minimal (grade 1), moderate (grade 2) or significant (grade 3). Normal and/or abnormal structures could be identified in images with Grade 1 and 2 noise. Identification of normal and/or abnormal structures was modified in images with grade 3 noise.

Overall image quality

The overall quality of pulmonary and mediastinal images in groups 1 and 2 was evaluated using a 3-point scale. The images with distinct anatomical details and without noise or with minimal noise were rated with a score of 1 (excellent quality image). The images with precise anatomical details and a slight increase in noise which did not affect the diagnostic value of the images were rated with a score of 2 (good quality image with no change in the precision of the diagnosis), while images with a marked increase in noise which affected the diagnostic value of the images were rated with a score of 3 (non-diagnostic image quality). When the scores for the pulmonary and mediastinal images of a given reconstruction were different, the worst image quality defined the overall score.

Calculation of the signal to noise (S/N) and contrast to noise (C/N) ratios

The relationships of signal to noise (S/N) and contrast to noise (C/N) were calculated using the method described by Szucs-Farkas et al. [17], using the following equations: $S/N = SI_{vx/noise}$ and $C/N = (SI_{vx} - SI_{muscle)/noise}$. The parameter SI_{vx} was the mean signal intensity (SI) of the pulmonary vessels; SI_{vx} was calculated as the mean vascular enhancement (in HU) obtained in 5 different areas (the pulmonary trunk, the right pulmonary artery, the left pulmonary artery, the right and left lower lobe pulmonary arteries); noise was defined as the mean standard deviation of these measures. The region-of-interest used for these measures was chosen so that it was as large as the vessels. The parameter SI_{muscle} corresponded to the mean attenuation of the central parts of the deep pectoral and spinal muscles on both sides.

Visibility of elementary lesions

To evaluate the potential impact of iterative reconstructions on the visibility of elementary lesions of pulmonary infiltration, we selected 3 pulmonary images from patients in group 1, each showing at least one of the following lesions: ground glass opacities, poorly-defined micronodules, well-defined micronodules, septal lines, non-septal lines, focal areas of hypoattenuation with (pulmonary cysts) or without (centrilobular emphysematous lesions) walls. The pulmonary images of the corresponding anatomical areas were studied in group 2 to evaluate the ability to detect the lesions and grade the visibility of the lesion as equivalent or less visible than those in group 1.

Image processing conditions

Evaluation of image quality was performed by consensus between 2 radiologists with 3 and 7 years of experience in pulmonary CT, respectively. FBP reconstructions were obtained using the CT data processing system. Raw data were transferred off-line to a computer provided by the manufacturer for iterative reconstructions. Reconstructed images were then transferred back to a clinical workstation for quantitative and qualitative evaluation of image noise. Images were read after they had been anonymized. For objective and subjective analysis of noise for a specific examination, the readers first analyzed the mediastinal images of the ''full-dose'', then of the ''low-dose'' examination placed side-by-side; this was followed by reading of pulmonary images in the same order. To detect elementary lesions, readers evaluated ''full-dose'' and ''low-dose'' pulmonary images simultaneously.

Statistical analysis

The design of this study can be summarized as follows:

- the main goal was to compare the quality of images from ''low-dose'' examinations reconstructed with SAFIRE reconstruction and ''full-dose'' images reconstructed by FBP;
- when this study was performed there were no data in the literature evaluating the quality of images in the same patient during the same CT pulmonary angiogram after a 60% reduction in radiation dose; therefore it was not possible to theoretically calculate the population;
- because of the frequency of dual source-single energy CT examinations in our routine clinical practice, we designed this investigation as an observational study over a period of 5 months corresponding to the duration of the availability of the prototype allowing reconstruction of each examination under the above-mentioned conditions.

The results were expressed as means and standard deviations for quantitative variables, frequencies and percentages for qualitative variables. For quantitative variables, comparison of the reconstruction techniques was obtained using the paired Student-*t* test. For qualitative variables, comparisons were made using the Chi^2 test. For comparison of the visibility of elementary elements of infiltration between the two groups, the percentage of CT sections in group 2 showing similar visibility of lesions to that in group 1 was estimated with a 95% confidence interval. Statistical analyses were performed with SAS software (version 9.3).

Results

Population characteristics

The characteristics of the study population were as follows: mean age (± standard deviation) 59.8 (± 16.3) years old (range: 18—81), mean weight (± standard deviation) 74.8 (± 17.4) kg (range: 48—125) and mean body mass index (BMI) (± standard deviation) 26.0 (± 5.3) kg/m^2 (range: 17.9—41.8). CT pulmonary angiography (a) identified the cause of dyspnea as a pulmonary embolism ($n = 6$), worsening

Table 1 Comparison of the quality of images between groups 1 and 2.

	Group 1 Images with standard dose FBP reconstructions	Group 2 Images with low-dose SAFIRE reconstructions	*P*
Objective noise			
In the trachea on mediastinal images Mean (SD), HU	17.66 (5.84)	16.04 (5.66)	0.0284[a]
In the aorta on mediastinal images Mean (SD), HU	33.04 (6.17)	33.67 (6.18)	0.4178[a]
In the trachea, parenchymal images Mean (SD), HU	37.96 (9.03)	29.77 (6.79)	<0.0001[a]
Signal/noise (S/N) ratio	9.77 (2.52)	9.86 (2.81)	0.4846[a]
Contrast/noise (C/N) ratio	7.80 (2.40)	7.88 (2.65)	0.4040[a]
Subject noise			
Mediastinal images			
Absent (score 0), *n* (%)	Score 0: 0	Score 0: 0	1[b]
Minimal (score 1), *n* (%)	Score 1: 37 (74%)	Score 1: 37 (74%)	
Moderate (score 2), *n* (%)	Score 2: 13 (26%)	Score 2: 13 (26%)	
Severe (score 3), *n* (%)	Score 3: 0	Score 3: 0	
Pulmonary images	Score 0: 0	Score 0: 0	
Absent (score 0), *n* (%)	Score 1: 40 (80%)	Score 1: 40 (80%)	1[b]
Minimum (score 1), *n* (%)	Score 2: 10 (20%)	Score 2: 10 (20%)	
Moderate (score 2), *n* (%)	Score 3: 0	Score 3: 0	
Severe (score 3), *n* (%)			
Overall image quality			
Excellent (score 1), *n* (%)	Score 1: 33 (66%)	Score 1: 33 (66%)	1[b]
Good (score 2), *n* (%)	Score 2: 17 (34%)	Score 2: 17 (34%)	
Non-diagnostic (score 3), *n* (%)	Score 3: 0	Score 3: 0	

[a] Student-*t* test for paired sample.
[b] Mac Neymar test.

of lesions due to lung disease ($n = 21$) and (b) did not find any cause for dyspnea in 23 patients.

The mean (±standard deviation) dose-length product (DLP) of the acquisitions was 265.2 (±78.2) mGy·cm (range: 122—506). The mean effective dose, calculated by multiplying the DLP by the conversion factor of 0.017 [18], was 4.51 (± 1.3) mSv (range: 2.1—8.6). The milliamperage was reduced by 60% in group 2; the corresponding theoretical dose of radiation was therefore reduced by 60%. Thus, the estimated mean theoretical dose of the DLP in group 2 was 106 mGy·cm, corresponding to a mean effective dose of 1.8 mSv.

Evaluation of image noise

Despite the dose reduction of 60% in group 2, a significant objective reduction of noise was observed in group 2 in the trachea on pulmonary images ($P < 0.0001$) and on mediastinal images ($P = 0.0284$) (Table 1). No significant difference was found between the two groups for the mean objective noise in the descending thoracic aorta on mediastinal images ($P = 0.4178$), with S/N ($P = 0.4846$) and C/N ($P = 0.4040$). There was no significant difference in the distribution of subjective noise scores for the pulmonary and mediastinal images in the two groups ($P = 1$).

Evaluation of the overall image quality

There was a similar distribution of scores for the overall image quality between groups 1 and 2 (Table 1). The overall image quality was considered to be excellent (score 1) in 66% of the cases (33/50); none of the series of images was graded as ''non-diagnostic''. Figs. 2, 3 and 4 illustrate the image quality that can be obtained with iterative reconstructions in different BMI.

Visibility of elementary lesions

A total of 147 lung images with at least one elementary infiltrative lesion were chosen in 49 patients in group 1; only one patient in this group did not have pulmonary infiltration. Comparative analysis of the elementary lesions in group 2 images is summarized in Table 2 with the following information:

- all elementary lesions identified in group 1 images were found in the corresponding group 2 images;

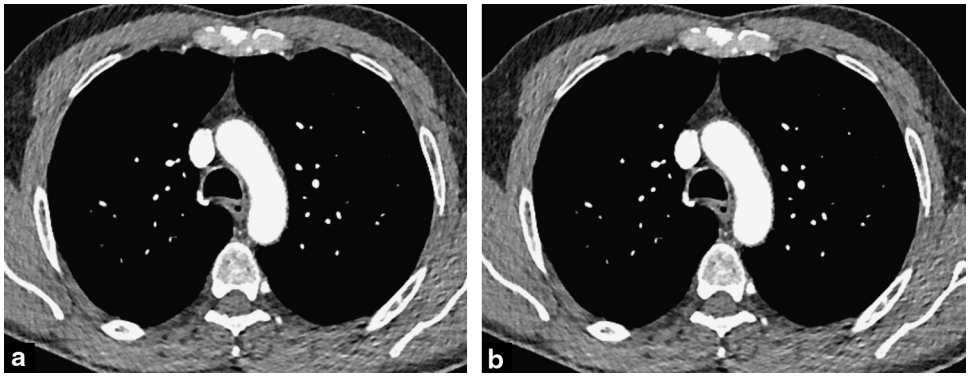

Figure 2. Comparison of group 1 and group 2 images in a patient with normal BMI (BMI = 23.5 kg/m^2). a: full-dose, mediastinal image obtained at the aortic arch by filtered back projection (FBP) reconstruction, showing the reference image quality: objective noise of the trachea: 13.6 HU; subjective noise graded as minimal. b: mediastinal image with 60% dose reduction, with SAFIRE reconstruction from the same anatomical area as (a). Note objective noise reduction measured at the trachea (11.2 HU). Subjective noise graded as minimum.

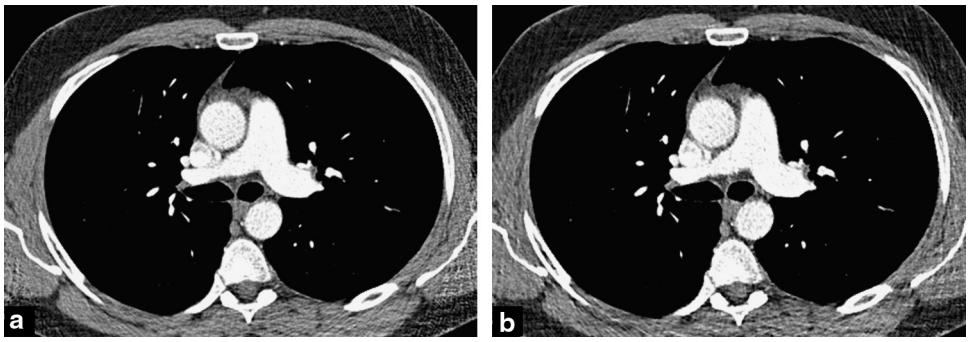

Figure 3. Comparison of group 1 and group 2 images in an overweight patient (BMI = 29.1 kg/m^2). a: full-dose mediastinal image obtained at the level of the pulmonary trunk, filtered back projection (FBP) reconstruction showing the quality of the reference image: objective noise of the trachea: 16 HU; subjective noise grade: moderate. b: mediastinal image with 60% dose reduction, SAFIRE reconstruction in the same anatomical area as (a). Note objective noise reduction in the trachea (13.4 HU). Subjective noise graded as moderate.

- visibility of the lesions in groups 1 and 2 were strictly identical for ground glass opacity, poorly defined micronodules and well defined micronodules;
- visibility of septal lines was similar in 31/32 sections (98.4%; CI 95% = [96.9%—99.9%]), non-septal lines in 103/105 sections (98.1%; CI 95% = [95.5%—100%]) and cysts or emphysematous lesions in 40/41 sections in group 2 (97.6%; CI 95% = [92.8%—100%]).

Discussion

Based on a methodology providing strictly similar test conditions for the two groups of images, our study shows that second generation iterative reconstruction (SAFIRE) results in an overall image quality of ''low-dose'' acquisitions that is similar to that of ''full-dose'' images reconstructed with FBP. The result is obtained with a dose reduction of 60%

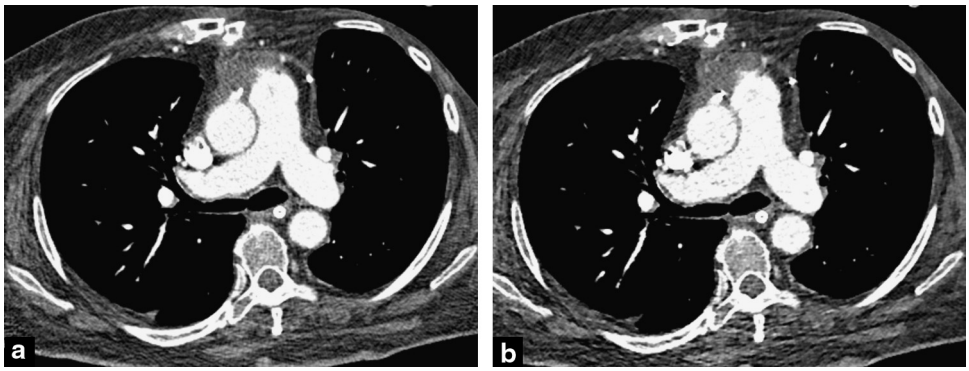

Figure 4. Comparison of group 1 and 2 images in an obese patient (BMI = 35 kg/m^2). a: full-dose mediastinal image obtained at the level of the pulmonary trunk, filtered back projection (FBP) reconstruction showing the quality of the reference image: objective noise in the trachea: 1.96 HU; subjective noise graded as moderate. b: mediastinal image with 60% dose reduction SAFIRE reconstruction of the same anatomical area as (a). Note the reduction in objective noise measured in the trachea (13.5 HU). Subjective noise graded as moderate.

Table 2 Comparative analysis of the visibility of elementary lesions in paired lung images from groups 1 and 2.

	Number of CT sections presenting elementary lesions in group 1	Number of CT sections presenting elementary lesions in group 2		Confidence interval 95%
		Visibility Identical	Inferior	
Ground glass opacity	56	56	0	
Micronodules with poorly defined borders	21	21	0	
Micronodules with well defined borders	1	1	0	
Septal lines	32	31	1	96.9%—99.9%
Non-septal lines	105	103	2	95.5%—100%
Cysts and emphysematous lesions	41	40	1	92.8%—100%

compared to the reference images, making it possible to consider using CT pulmonary angiogram in routine practice with a mean DLP of 106 mGy·cm and a mean effective dose of 1.8 mSv. These results support the comparison with recent reports of a mean effective dose of 7 to 8 mSv in the literature [19,20].

This image quality, which was rated as good or excellent in all cases, resulted from the possibility of reducing noise in group 2 images. The objective noise was evaluated in two anatomical areas, in particular the trachea in the upper third of the thorax, as usually reported in the literature, as well as the descending thoracic aorta in the lower third of the thorax. The objective noise measured in the trachea was significantly reduced on pulmonary and mediastinal images in group 2. There was no statistically significant difference in objective noise in the aorta between the two groups, suggesting the positive impact of iterative reconstruction in anatomical regions characterized by the presence of highly attenuated structures. Despite the applied dose reduction, there was no significant difference in the S/N ratio and the C/N ratio between groups 1 and 2.

Because first-generation iterative reconstructions generated smoothed images [21], our study analyzed the impact of image quality on lesion detection following iterative reconstruction. The technical conditions of our protocol were well adapted to this comparative analysis, because the patient was his/her own control in the same space and time. Our analysis focused on elementary lesions of pulmonary parenchymal infiltration which are usually small and whose visibility can be altered by increased noise or low-dose images. Of note all elementary lesions identified in group 1 images were found in the corresponding group 2 images, with no significant difference in visibility between the two groups. This confirms that the diagnostic value of images obtained with the iterative reconstruction algorithm from low-dose sequences is preserved. Despite a different methodology and evaluation of different iterative reconstruction algorithms (ASIR and MBIR versus SAFIRE), our results are similar to those reported by Katsura et al. who compared the visibility of poorly defined and well-defined pulmonary nodules [22].

Our study has several limitations that should be mentioned. First, we used that same CT parameters for all included patients, whatever their weight and BMI. While this approach could induce a higher noise level in obese patients, it should be noted that all of the series of images were considered to be of diagnostic quality. Second, the research protocol that we used, based on a reduction of miliamperage between the different series of images did not allow us to jointly evaluate the impact of SAFIRE on low-dose images with a reduction in kilovoltage. Considering the efficacy of a reduction in kilovoltage on the delivered dose and the quality of contrast enhancement, it would be logical to imagine applying iterative reconstructions to examinations acquired with low kilovoltage especially in young adult populations, women, and children. Finally our analysis included simultaneous analysis of ''full-dose'' and ''low-dose'' images at each examination which could have introduced a bias in the subjective evaluation of image quality. This simultaneous analysis had the advantage of providing a rigorous comparison of objective noise by reproducing a region-of-interest with an identical surface, in the same anatomical area in the different series of images obtained from the same patient. Moreover, this methodology allowed a comparative analysis of the visibility of elementary lesions of infiltration of the pulmonary parenchyma in the same sequences.

Conclusion

Despite a dose reduction of 60%, the iterative reconstruction algorithm that was evaluated (SAFIRE) provided an objective noise reduction and subjective image quality that was identical to ''full-dose'' images reconstructed by filtered back projection. Because of the quality of these images, there was no impact on the detection of elementary lesions of infiltration or destruction of the lung parenchyma.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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